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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

L-310

WIND-TUNNEL TESTS OF HINGE-MOMENT CHARACTERISTICS OF SPRING-TAB AILERONS

By Frederick H. Imlay and J. D. Bird

SUMMARY

Brief tests were made in the NACA stability tunnel of two types of spring tab used as balances on a partial-span plain aileron. The tabs were connected to a spring so located in the control system that the tab deflection was dependent on the control force. One tab was formed by making the rear portion of the aileron movable; the other tab was detached and located a distance of 1 aileron chord behind the aileron. The aileron was mounted on a wing of 4-foot chord and of NACA 23012 section. The wing completely spanned the 6-foot-square test section of the tunnel. The tests were run at angles of attack of 0° and 9.5° and at dynamic pressures of 25 and 65 pounds per square foot. The effects of changes in spring preload and of removing the tab-gap seal were investigated for the trailing-edge tab. The test results, uncorrected for tunnel-wall or blocking effects, presented as curves of tab angle, aileron angle, and hinge-moment coefficient at the control stick, are plotted against stick deflection. The change in section lift coefficient with stick deflection was estimated and included with the plots of the test results. Cross plots of control-hinge-moment coefficient against computed increment of section lift coefficient are also included. The results of the tests indicated that spring tabs offer a very promising method of reducing the control forces without danger of causing overbalance or insufficient balance under any flight condition.

INTRODUCTION

The increased size and speed of present-day airplanes have made necessary a very close balance of hinge moments if the lateral-control surfaces are to furnish the rolling velocities demanded and still are to be moved manually. The wide variation in the forms of balance employed is indicative of the lack of any completely satisfactory method of balance. The reduction in control force provided by the balance is usually accompanied by one or more disadvantages, such as insufficient balance or overbalance for some flight conditions, reduction in control effectiveness, loss of "feel" in the control, or lag in the response to control movement.

The ideal aileron balance would be one in which the amount of balance would depend directly upon the stick force. In an attempt to achieve this ideal, the use of spring tabs for balancing has been proposed. Theoretical calculations (references 1 to 3) and flight observations (reference 4) have suggested the value of such systems.

The spring tab receives its name from the use in the control system of a spring, the deflection of which is dependent on the control force. The deflection of the spring in turn moves a tab at the rear of the aileron in such a way that the stick forces produced by the aileron are reduced. The deflection of the tab can be delayed until the stick force exceeds a certain value if the spring is preloaded.

By using a tab for balance, several advantages, such as improved control effectiveness and decreased drag, are obtained over the usual types of balance located at the aileron nose. The tab balance also lightens the load on the aileron hinges and reduces the overhang of the aileron hinges.

The tests reported herein were made to permit qualitative comparisons of various spring-tab ailerons with a plain aileron. The effects of tab location, amount of control deflection, airspeed, angle of attack, spring preload, and tab-gap seal were investigated. For purposes of discussion, each change in spring preload or in the condition of the tab gap is considered a separate spring-tab arrangement. In order to permit comparison of the control forces at the same control effectiveness, estimates were made of the change in section lift coefficient with control-stick deflection for the plain aileron and for the aileron with various spring-tab arrangements.

The influence of the spring tab on the response of the control surface to sudden stick deflections was also investigated.

SYMBOLS

The following symbols and subscripts are used:

V free-stream velocity

ρ density of air

q free-stream dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

b span

c chord

δ angular deflection of aerodynamic surface; positive when trailing edge moves down

H control-hinge moment; that is, moment exerted at control-stick hinge by aerodynamic surfaces; positive when moment tends to produce positive θ_s

C_h control-hinge-moment coefficient $\left(\frac{H}{q{c_a}^2 b_a}\right)$

l airfoil section lift

c_l airfoil section lift coefficient $\left(\frac{l}{q c_w}\right)$

Δc_l change in c_l due to deflections of aerodynamic surfaces

α geometric angle of attack, measured between tunnel axis and airfoil chord

θ_s angular deflection of control stick; positive for positive δ_a

Subscripts:

w airfoil section with aileron and tab

a aileron section with tab

t tab section alone

TEST CONDITIONS AND APPARATUS

The tests were conducted in the 6-foot-square test section of the NACA stability tunnel. The model used was a rectangular wing of 4-foot chord with an NACA 23012 section and completely spanned the test section. Because the tests were intended to be used only for comparative purposes and did not involve the measurement of forces or moments on the wing, no attempt was made to conform accurately to the NACA 23012 section. The size and location of the partial-span aileron and the sizes and locations of the trailing-edge and detached spring tabs used are shown in figure 1. The chords of the aileron and the detached tab sections were alined when the tab angle was zero. The aileron section departed from the NACA 23012 profile by having a straight taper from the aileron hinge line to the trailing edge. (See fig. 2.) The aileron and trailing-edge-tab gaps were sealed with plastic-impregnated cloth, attached with glue in the positions indicated in figure 2.

The principle of operation of the spring-tab linkage is illustrated in the schematic diagram of figure 3, and details of the specific linkage tested are given in figure 4. For convenience in interpreting the results, the spring-tab linkage was assumed to be connected directly to the horn on a control stick, as noted in figures 3 and 4. The deflection of the spring, located between the aileron horn and the control stick, was proportional to the aileron hinge moment if the force transmitted by the spring exceeded the spring preload. The spring constant was 369 pounds per inch. The spring was preloaded by shortening the spring-retaining bolts. The distance from the aileron horn to the control stick, and consequently the mechanical advantage of the control stick, varied slightly with the spring deflection. As indicated in figure 3, the tab was so linked into the control system that the tab deflection was proportional to the deflection of the spring.

Hinge moments at the assumed control-stick location were measured by a calibrated spring balance. In order to deflect the aileron, torque was applied manually to the actual control stick located outside the test section and was transmitted through the moment balance and a torque tube to the arm labeled "control horn" in figure 3. The angular deflections of the aileron, tab, and control horn were read on calibrated quadrants. Measurements of the hinge moments could be repeated to give hinge-moment coefficients agreeing within ±0.002 at $q = 25$ pounds per square foot and ±0.001 at $q = 65$ pounds per square foot. The accuracy of the angular deflections is believed to be $\pm 1/2^{\circ}$.

L-318

RESULTS AND DISCUSSION

The outstanding impression gained during the tests of the spring-tab ailerons was the ease with which the aileron could be deflected at high speeds. The control force required for full aileron deflection seemed little higher at the maximum speed than at the lower speed. In contrast, the extent to which the plain aileron could be deflected became very limited because of the high control force at the high speed.

A moderate oscillatory motion of the control system occurred under some test conditions when the tab was near the stall. The oscillation appeared to be caused by unsteady flow conditions such that the tab became alternately stalled and unstalled. Motions of this type have been observed during tests of other types of aileron balance. For the detached tab, the stall was usually accompanied by an abrupt change to a new equilibrium condition at a lower aileron angle and a higher tab angle than before the stall. Stalling of the tab undoubtedly should be avoided by use of adequate tab size in order that large deflections are not required or by use of a limited tab-angle travel.

The results of the tests are presented in figures 5 to 8, which show the variation of tab angle, aileron angle, increment of section lift coefficient, and control-hinge-moment coefficient with control-stick deflection for the plain aileron and for the aileron with various trailing-edge-tab arrangements. The test data for the aileron with a detached spring tab are presented in figures 9 to 12. The various curves show different stick positions for zero hinge moment, an indication that the floating angle of the aileron changed with speed for any given tab arrangement. The variation with speed occurred because the weight of the aileron, tab, and control-operating linkage introduced an initial moment about the aileron hinge line. Because this weight moment was constant, the floating angle of the aileron varied with speed and angle of attack.

An additional variation in floating angle for the different tab arrangements resulted from slight differences in the tab-angle setting corresponding to zero aileron deflection. Modification of the test results to compensate for the weight moment and for tab-setting changes was considered not to facilitate comparisons of the behavior of the aileron with and without the spring tabs sufficiently to warrant the additional computations required. The greatest effect of such modification would be to shift the tab-angle and hinge-moment-coefficient curves along the stick-deflection scale until the floating angle was the same for all test conditions.

Mechanical limitations of the control system prevented testing of the plain aileron over a sufficient range of stick position for satisfactory comparison with results for the spring-tab ailerons; data of reference 5 were therefore used to extend the curves for the plain aileron, as indicated by the dashed lines in figures 5 to 12. Reference 5 was also used to obtain data for computing the curves of the increment of section lift coefficient presented in these figures.

The effect of spring preload is shown in figures 5 to 12 by the tendency of the curves for the spring-tab ailerons to match the corresponding curves for the plain aileron over the range of stick position for which the load in the spring link does not exceed the preload in the spring. The value of C_h at which the hinge-moment-coefficient curve breaks is indicative of the amount of spring preload. The amount of preload for the curves labeled "large preload" differed for the trailing-edge tab and the detached tab. Tests of the trailing-edge tab were made at small preload in addition to the tests at large preload. The data obtained readily permit conclusions to be drawn concerning the behavior of spring-tab ailerons with no preload. With no preload, the slope of the hinge-moment-coefficient curve would be lower than for the plain aileron throughout the range of stick position. Preloaded spring-tab ailerons, on the other hand, have a hinge-moment-coefficient curve that is the same as for the plain aileron over the central portion of the stick travel; for larger stick deflections, however, the curve has about the same slope as the hinge-moment-coefficient curve for a corresponding spring-tab aileron with no preload. The advantage of the preloaded tab in reducing the hinge moments only when the stick force is large may be contrasted with the usual behavior of aerodynamic balances, which reduce the hinge moment most at small control deflections for which the control is already sufficiently light.

The increment of section lift coefficient produced by a given stick deflection gives an indication of the relative effectiveness of the various control systems in producing rolling motion. The curves in figures 5 to 12 show that the plain aileron furnishes the greatest amount of control, provided the pilot is able to deflect the aileron to the required angle. The spring-tab aileron with no preload, in contrast, gives the least amount of control. The pilot's strength, however, is usually the governing factor that limits the amount of control attainable with any particular system. Cross plots showing the control-hinge-moment coefficient required to produce a given increment of section lift coefficient for the various trailing-edge-tab arrangements are presented in figures 13 and 14 for the two test speeds and for an angle of attack of 0°. These figures indicate that a spring-tab aileron with no preload will generally develop the largest amount of control for a given effort on the part of the pilot. For positive control deflections at low speed, however, the spring-tab ailerons gave little or no gain over the plain aileron. (See fig. 13.)

Although figures 13 and 14 indicate that the spring tab decreases the hinge-moment coefficient of the aileron for a given value of Δc_l, a considerable increase in the required stick deflection usually attends the reduction in hinge-moment coefficient. The increase in stick deflection has two causes: (1) More aileron deflection must be produced to make up for the loss of lift caused by deflecting the tab, and (2) part of the available stick travel is required to deflect the tab, that is, to compress the spring. If it is assumed that the original control gearing required all the available stick travel to attain full aileron deflection, two methods are available for accommodating the increased travel demanded when the spring tab is introduced: (1) The control gearing may be left unaltered and the condition accepted that the spring-tab aileron cannot attain the same aileron deflection at high speeds as is potentially possible with the plain aileron. With such an arrangement, nevertheless, the spring-tab aileron may provide considerably more actual control at high speeds because the pilot is able to attain control deflections that he otherwise would not have the strength to achieve. (2) The mechanical advantage of the control stick may be decreased to permit full aileron deflection with the spring fully compressed. If the mechanical advantage is decreased, an increase occurs in the stick force for any given operating condition.

A reduction in the stick travel expended to compress the tab spring would be desirable. Two methods of reducing the travel would be (1) to make the spring stiffer and obtain the tab deflection by a larger multiplication of the spring movement, or (2) to obtain part of the tab movement by direct gearing and to use the spring deflection to produce the rest of the tab movement. As an alternative, the amount of tab deflection, and consequently the stick travel, needed could be reduced if some other method of balance were used to supplement the tab balance.

Determination of the effect of speed on the control forces experienced with the spring-tab aileron is of particular interest but requires comparisons of the actual hinge moments involved. Such a comparison is given in figure 15, in which the control-hinge moment is plotted against speed for the plain aileron and for the aileron with sealed trailing-edge tab with both small and large spring preloads. Figure 15 was cross-plotted from figures 13 and 14 for a change in Δc_l of -0.4 from the position of zero hinge moment. The values obtained show that the hinge moment of the plain aileron varies as the square of the speed but that the spring-tab aileron tends to give a nearly constant rate of increase of hinge moment with speed. Gates theoretically predicted in reference 1 that such results would be obtained. The rate of increase of hinge moment with speed can be changed by variations in parameters, such as the spring constant, for the spring-tab system.

L-318

For a preloaded spring-tab aileron, another effect of an increase in speed is the reduction of the range of stick travel over which the preload is evident. In figure 7, for example, the effect of preload is apparent at values of control-stick deflection from approximately -12° to 7° for the spring-tab aileron with large preload at $q = 25$ pounds per square foot. For the same spring-tab aileron at the higher speed corresponding to $q = 65$ pounds per square foot (fig. 8), the approximate range of stick deflection affected by the preload is from -11° to -3°; and, contrasted with figure 7, the curves more nearly approach the curves that would be obtained for a spring-tab aileron with no preload. These results indicate that a preloaded spring-tab aileron operated within a sufficient speed range will act as a plain aileron over the entire range of stick deflections at the lower speeds and will behave much the same as a spring-tab aileron with no preload at the higher speeds.

Removal of the tab seal reduced the effectiveness of the tab as a hinge-moment balance, as evidenced by the larger tab deflections required for a given aileron deflection when no tab seal was used. (See figs. 5 to 8.) Higher stick forces were necessarily required to produce the larger tab deflections.

During the tests with the tab seal removed, a tendency of the tab to stall at moderately low deflections was noted. The stalling tendency appeared to be considerably influenced by the Reynolds number. A comparison of the tab-angle curves for the unsealed tab with small preload in figure 7 and 8 shows that a tab angle of -22° was reached at low speed but that the tab stalled above an angle of -17° at high speed.

In practice, difficulty may be experienced in sealing the tab gap. The foregoing discussion indicates that without such a seal the trailing-edge spring tab suffers an appreciable loss in efficiency. A few tests were therefore conducted of an aileron with a detached spring tab, which requires no seal. Test results for the detached tab, presented in figures 9 to 12, are cross-plotted in figures 16 and 17 to show the control-hinge-moment coefficient that must be overcome to obtain a given increment of section lift coefficient.

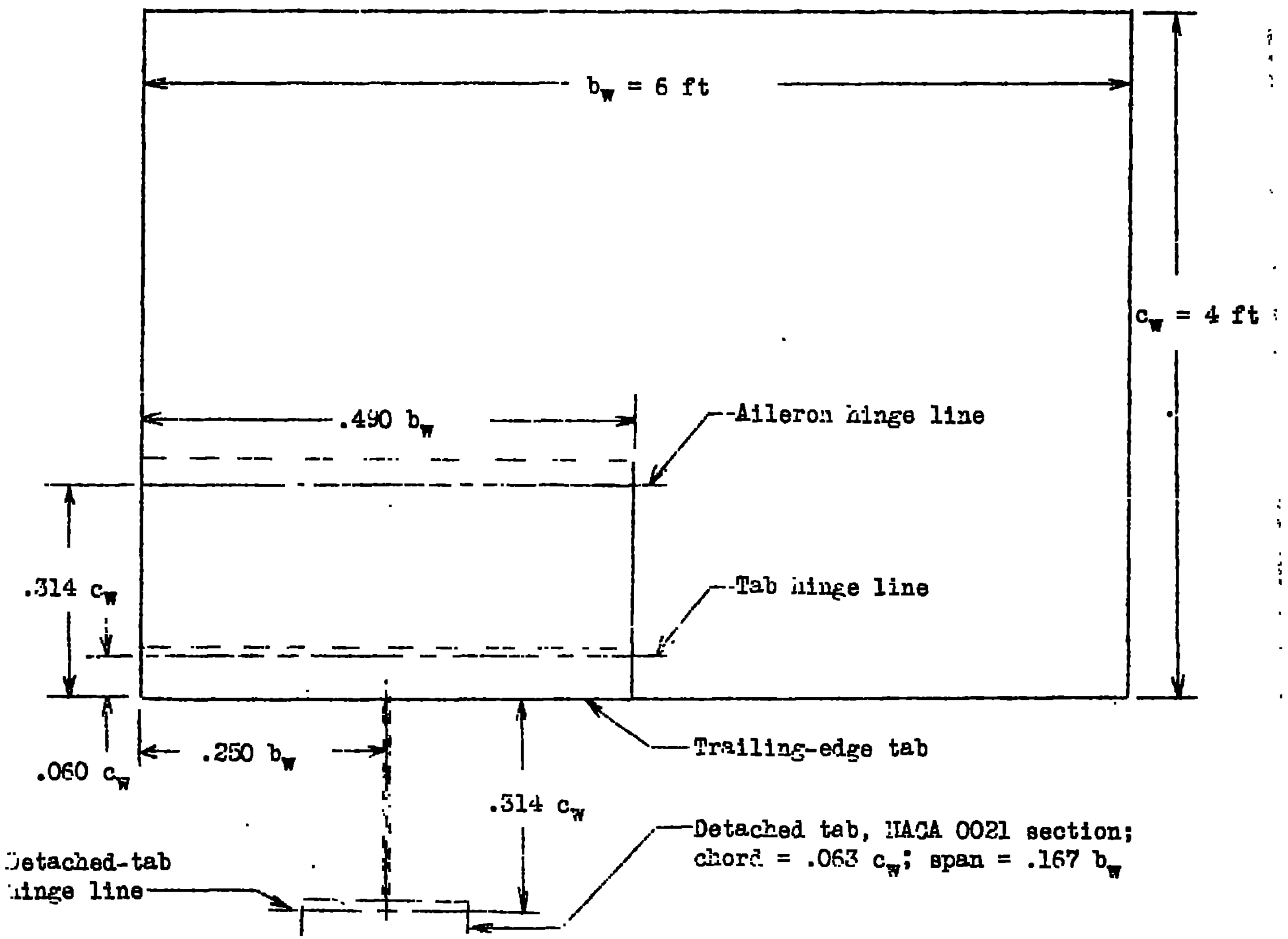


Figure 1.- Sizes and locations of aileron and tabs tested.

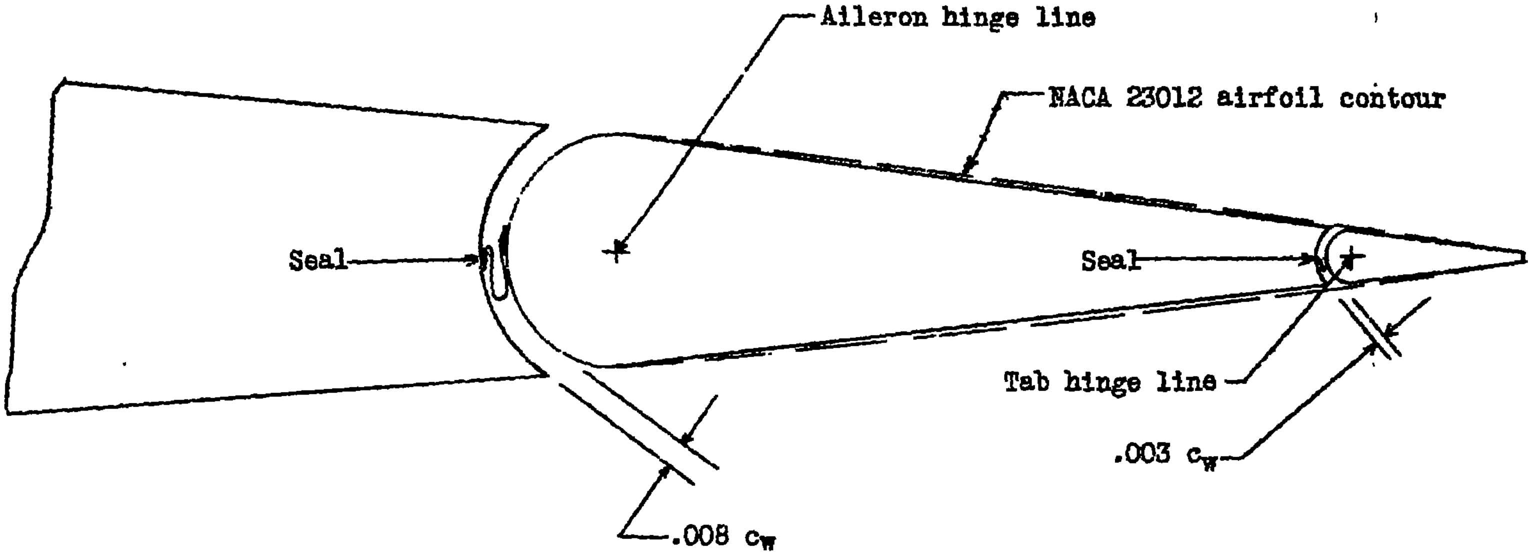
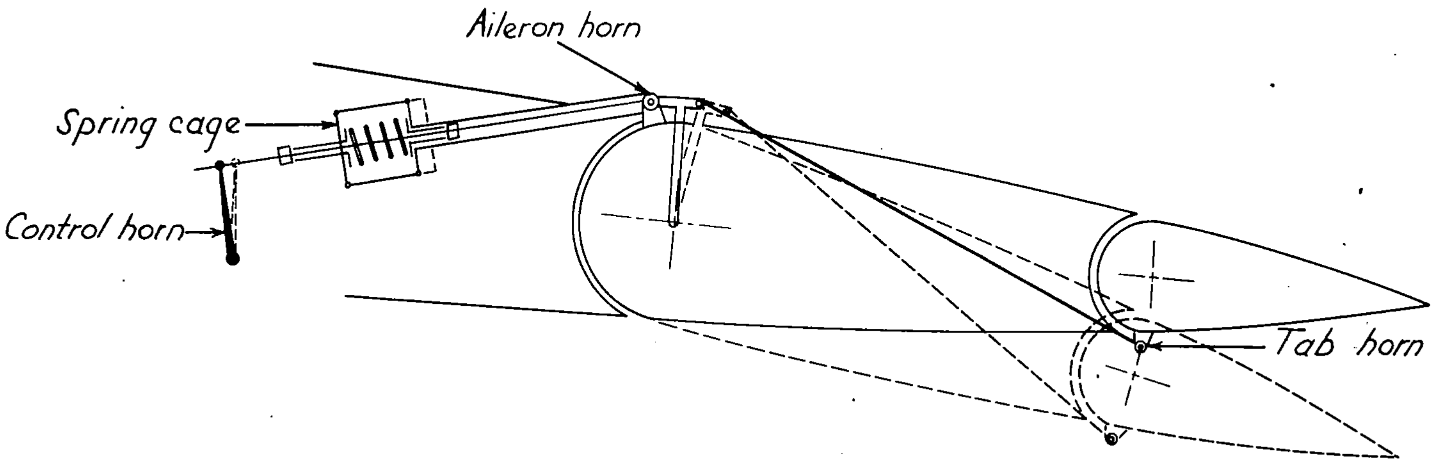
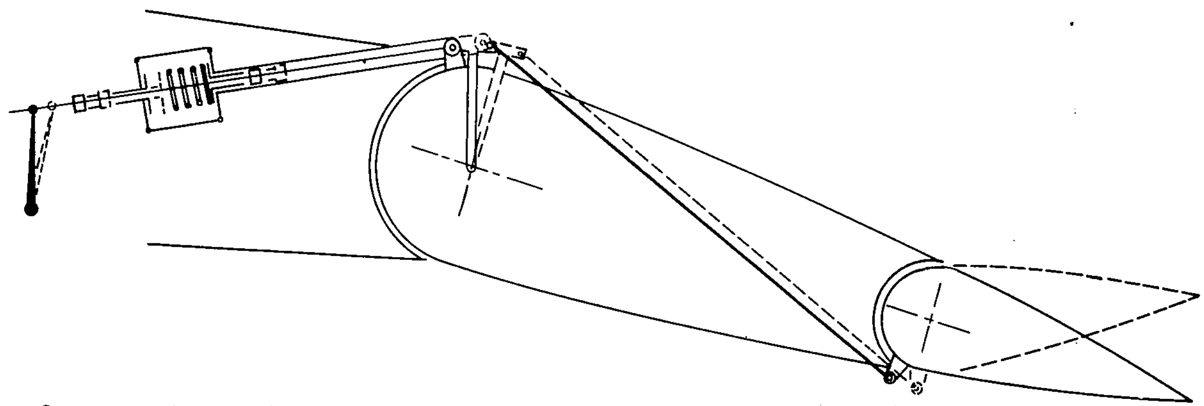


Figure 2.- Cross section of aileron and trailing-edge tab.



(a) Mode of operation when control force does not exceed spring preload.



(b) Mode of operation when spring is compressed to deflect tab.

Fig. 3-Schematic diagram showing principle of operation of spring tab linkage.

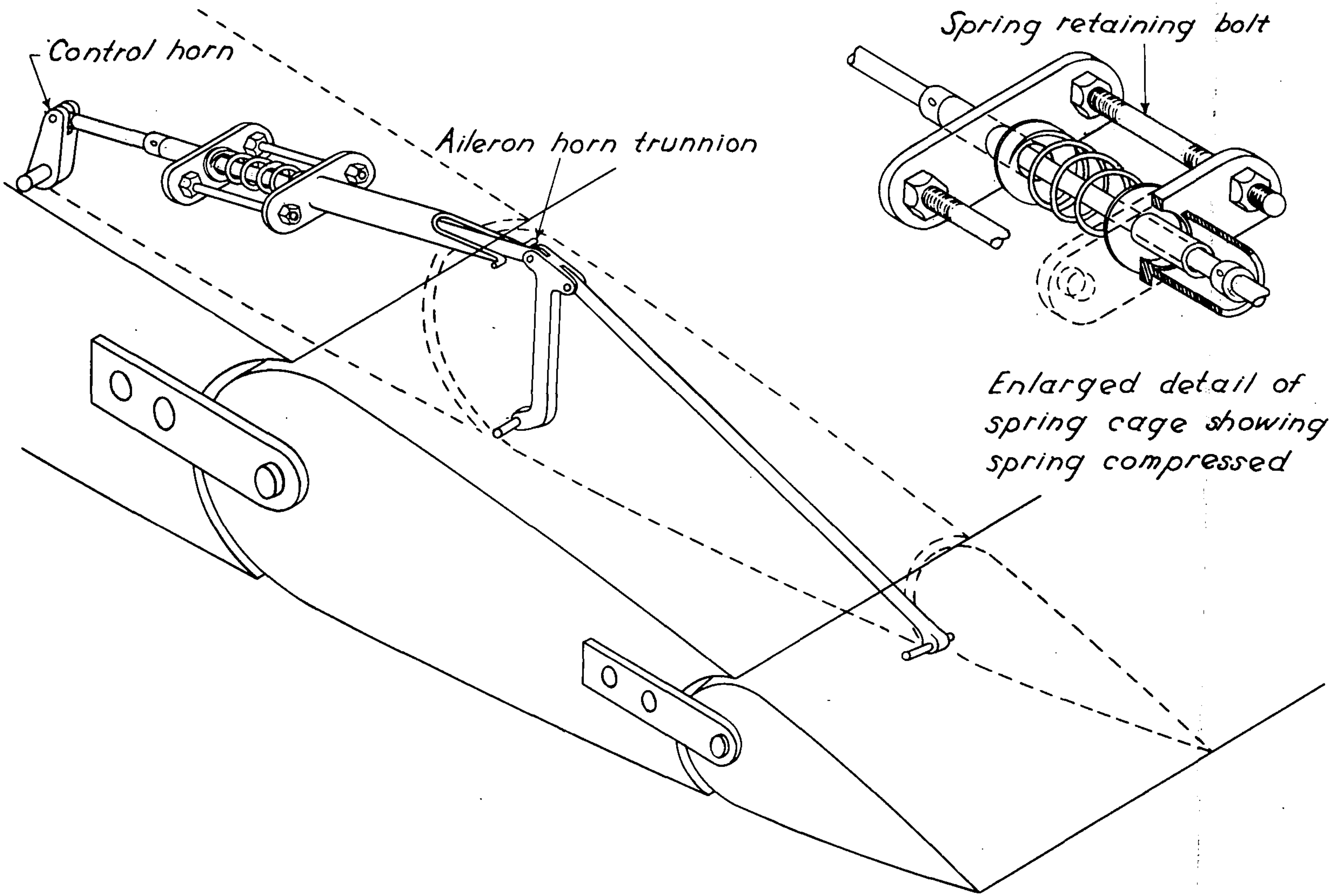


Figure 4.- Details of spring tab linkage tested.

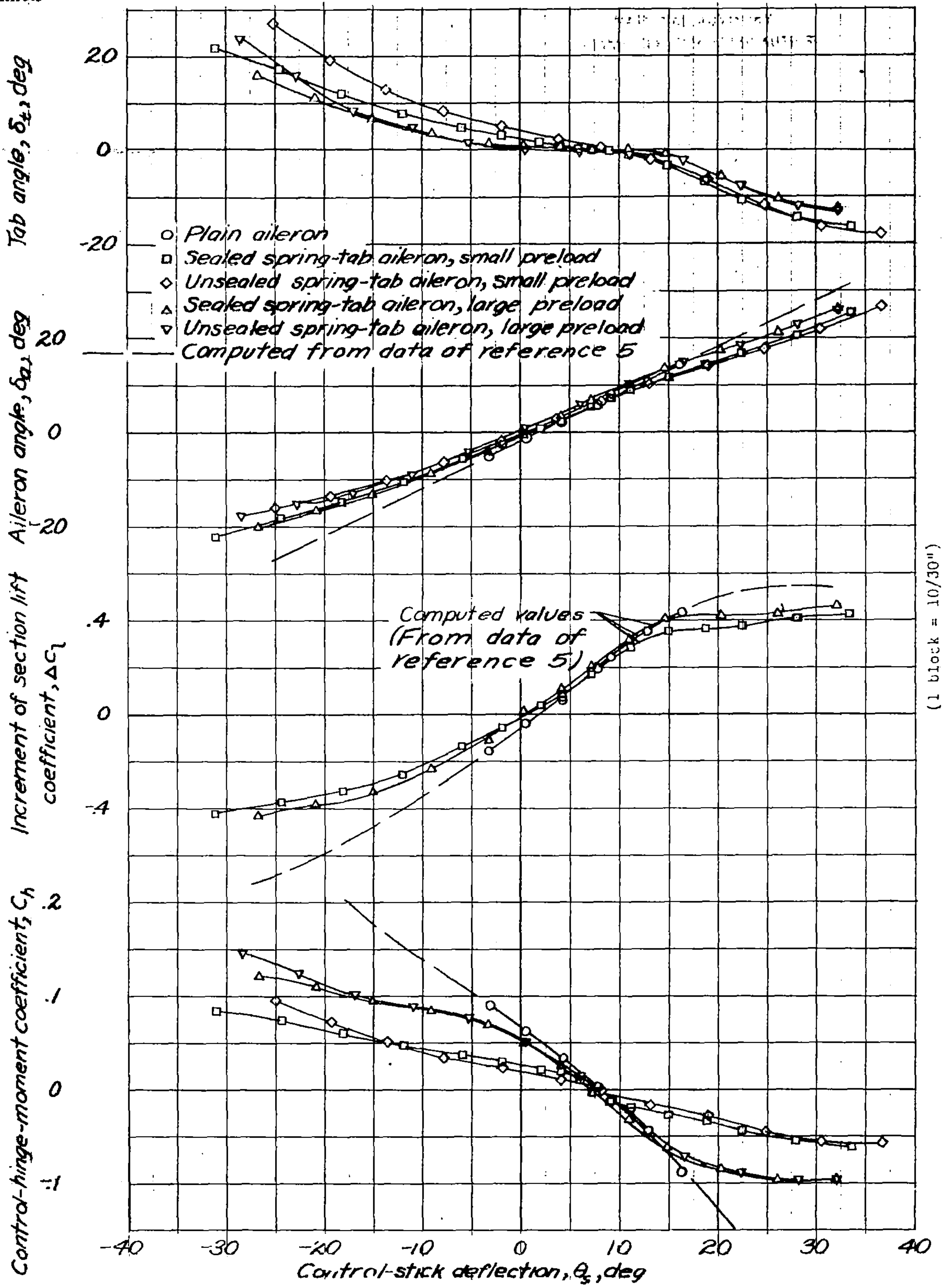


Figure 5. - Variation of tab angle, aileron angle, increment of section lift coefficient, and control-hinge-moment coefficient with control-stick deflection for plain and spring-tab ailerons. $\alpha = 0°$; $q = 25$ pounds per square foot.

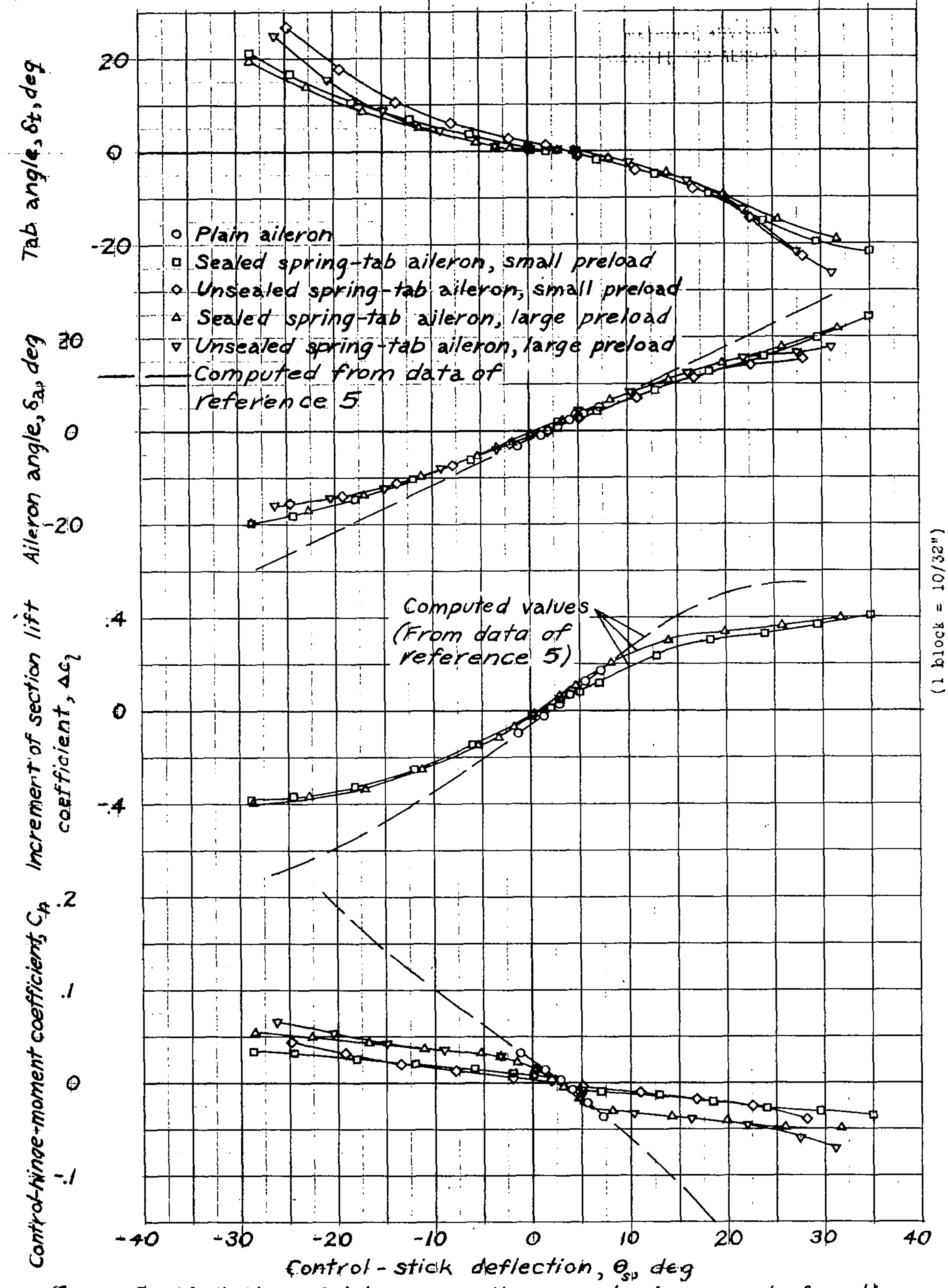


Figure 6.- Variation of tab angle, aileron angle, increment of section lift coefficient, and control-hinge-moment coefficient with control-stick deflection for plain and spring-tab ailerons $\alpha = 0°$; $q = 65$ pounds per square foot.

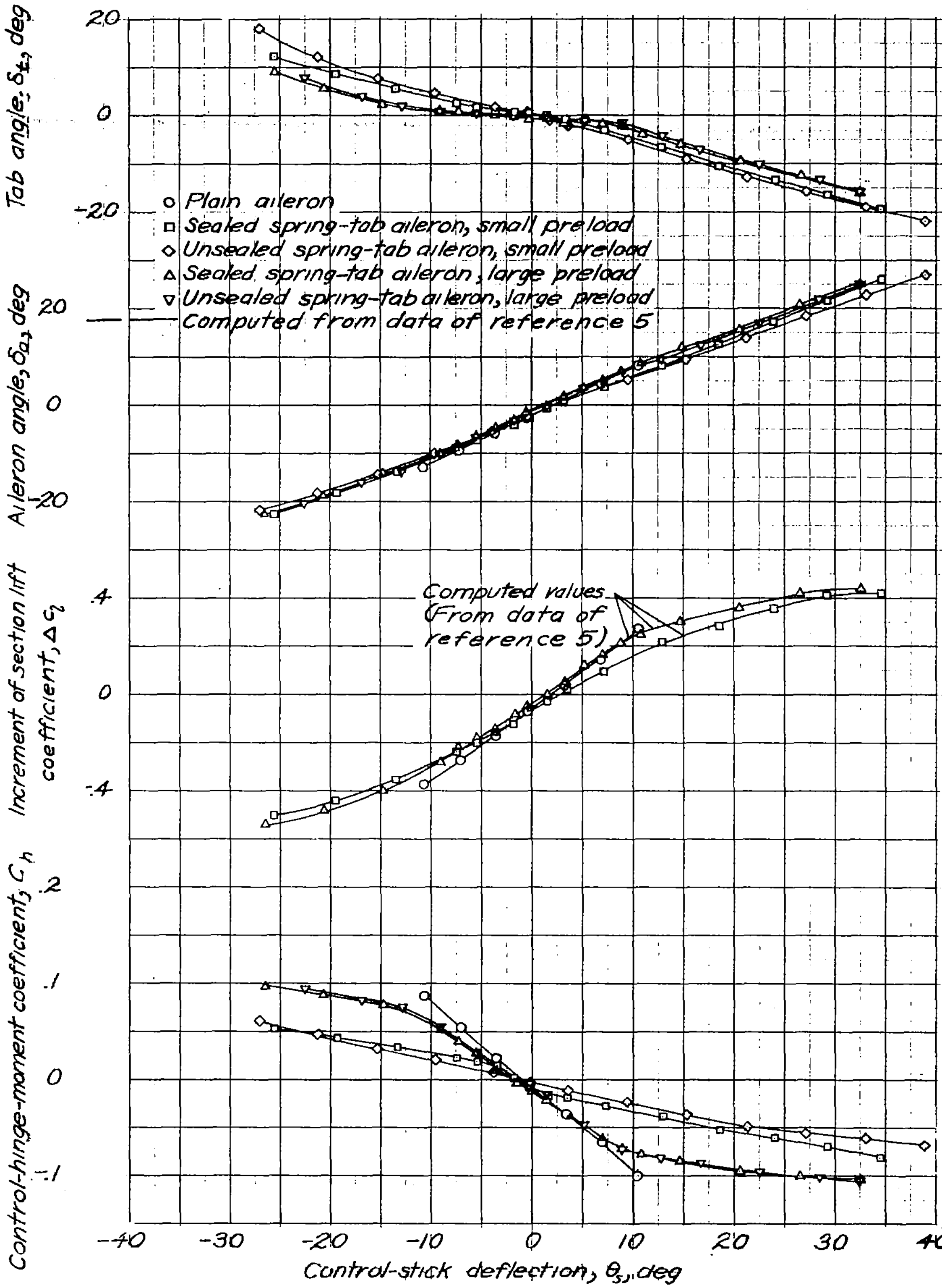


Figure 7. – Variation of tab angle, aileron angle, increment of section lift coefficient, and control-hinge-moment coefficient with control-stick deflection for plain and spring-tab ailerons. $\alpha = 9.5°$; $q = 25$ pounds per square foot.

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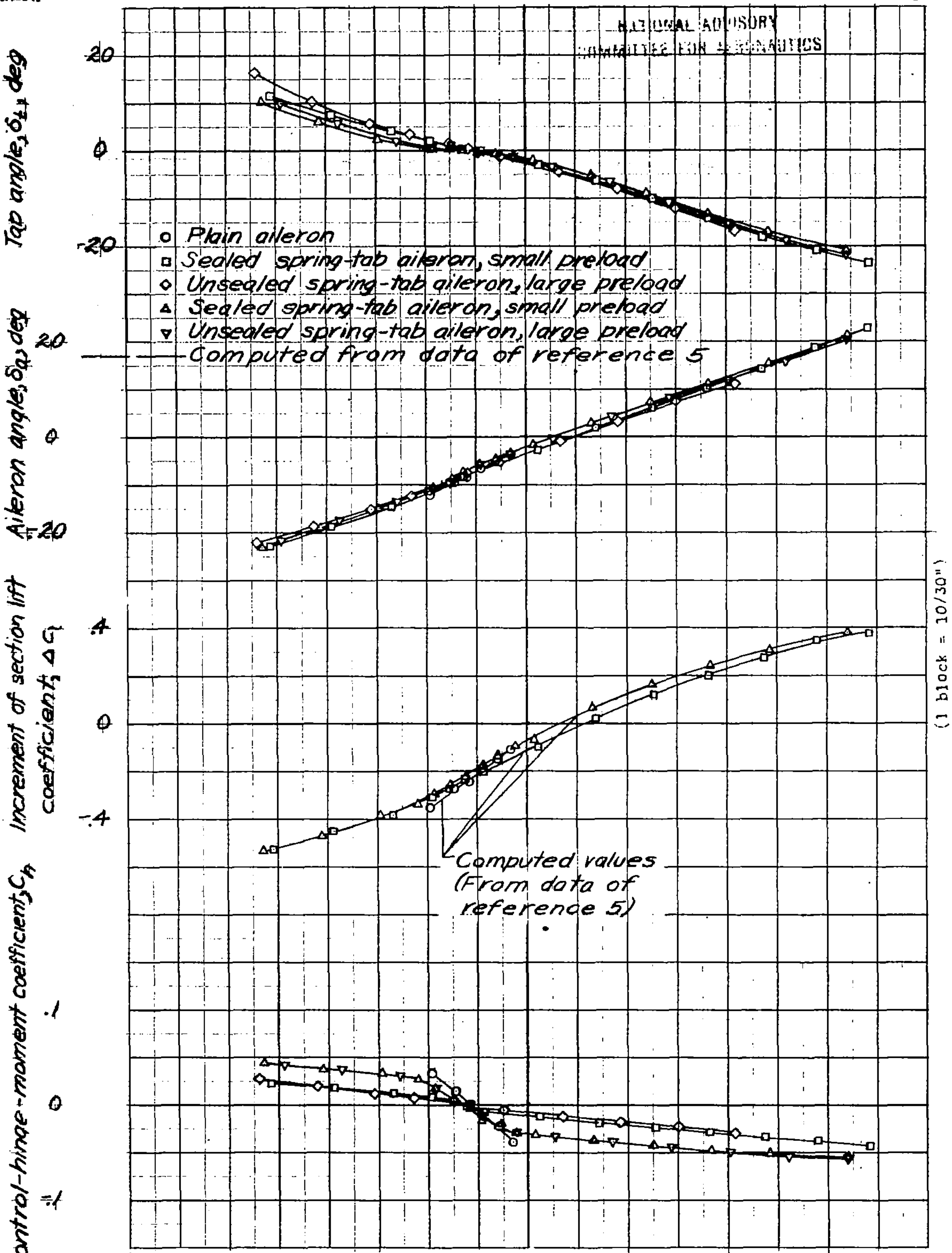


Figure 8. -Variation of tab angle, aileron angle, increment of section lift coefficient, and control-hinge-moment coefficient with control-stick deflection for plain and spring-tab ailerons. $\alpha = 9.5^{\circ}$; $q = 65$ pounds per square foot.

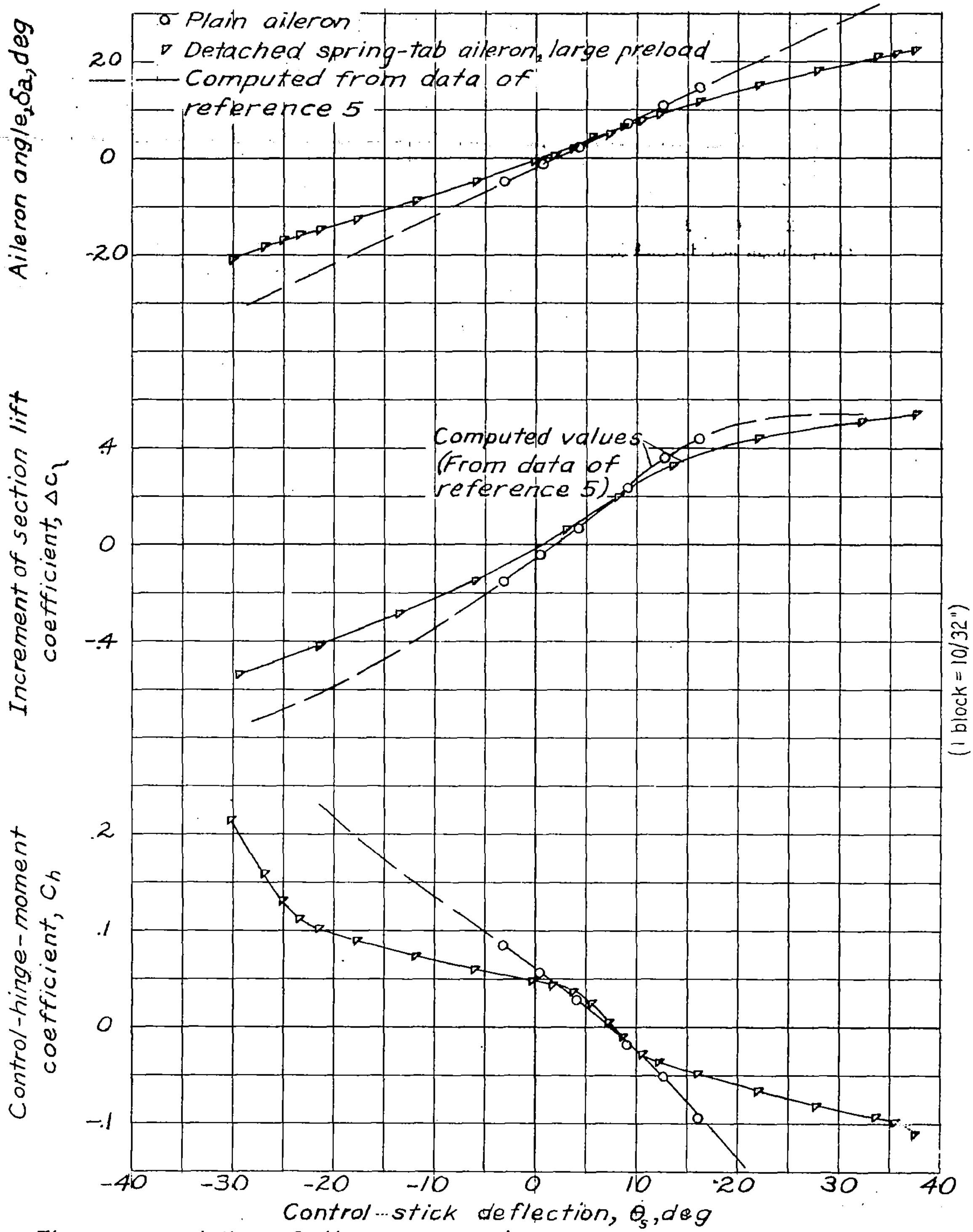


Figure 9.- Variation of aileron angle, increment of section lift coefficient, and control-hinge-moment coefficient with control-stick deflection for plain and detached spring-tab ailerons. $\alpha = 0^{\circ}$; $q = 25$ pounds per square foot.

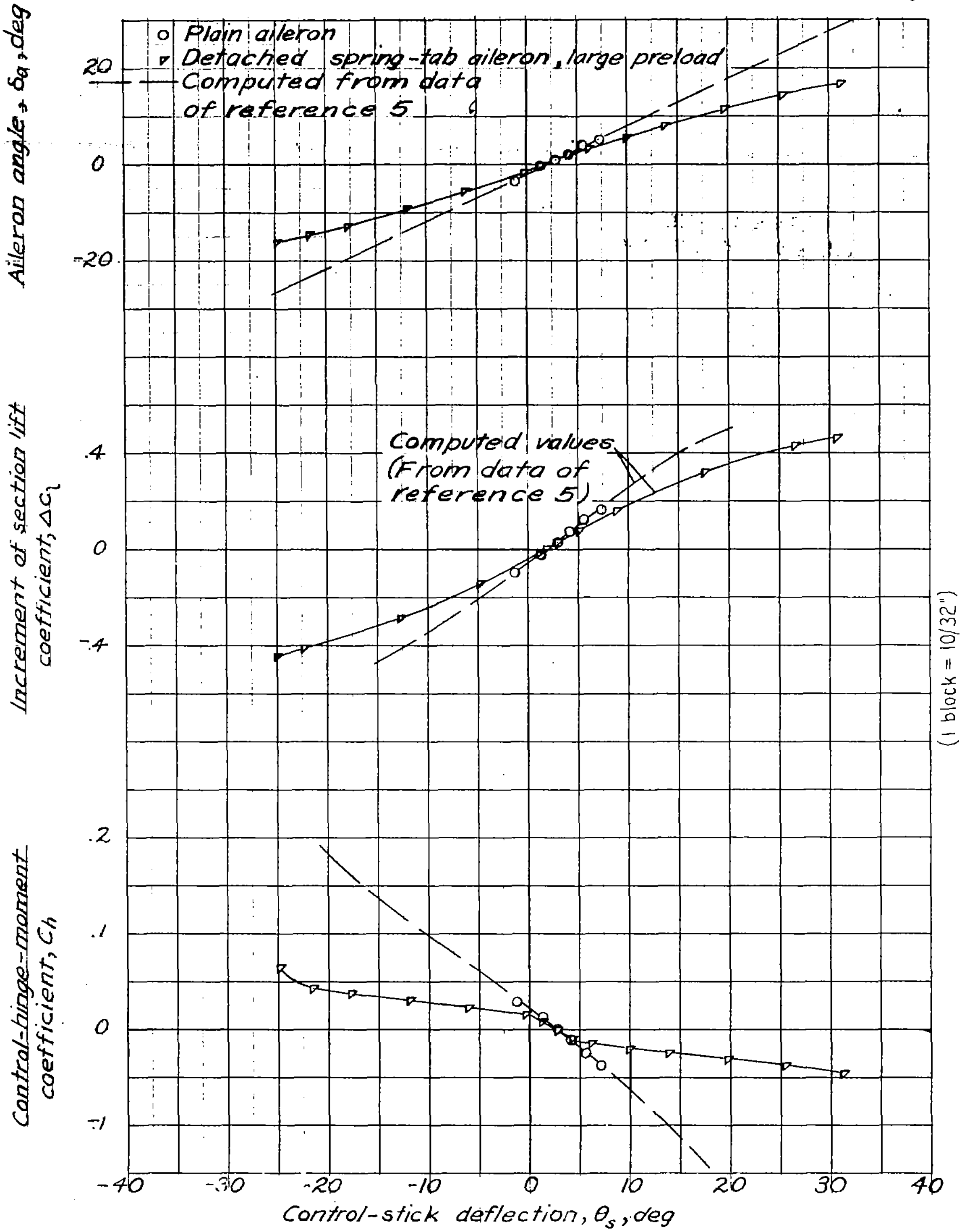


Figure 10. - Variation of aileron angle, increment of section lift coefficient, and control-hinge-moment coefficient with control-stick deflection for plain and detached spring-tab ailerons. $\alpha = 0°$; $q = 65$ pounds per square foot.

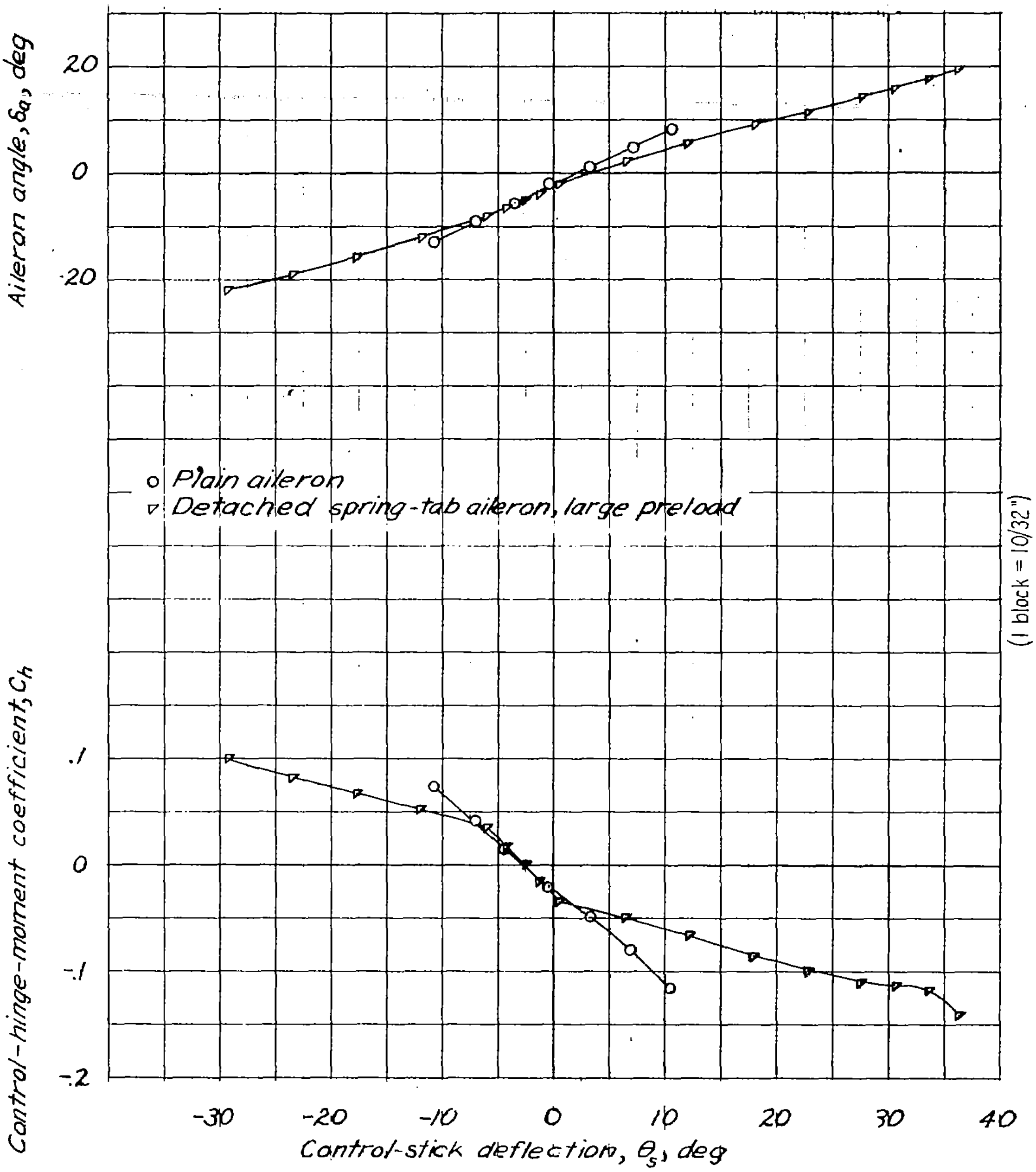


Figure 11. - Variation of aileron angle and control-hinge-moment coefficient with control-stick deflection for plain and detached spring-tab ailerons. $\alpha = 9.5°$; $q = 25$ pounds per square foot.

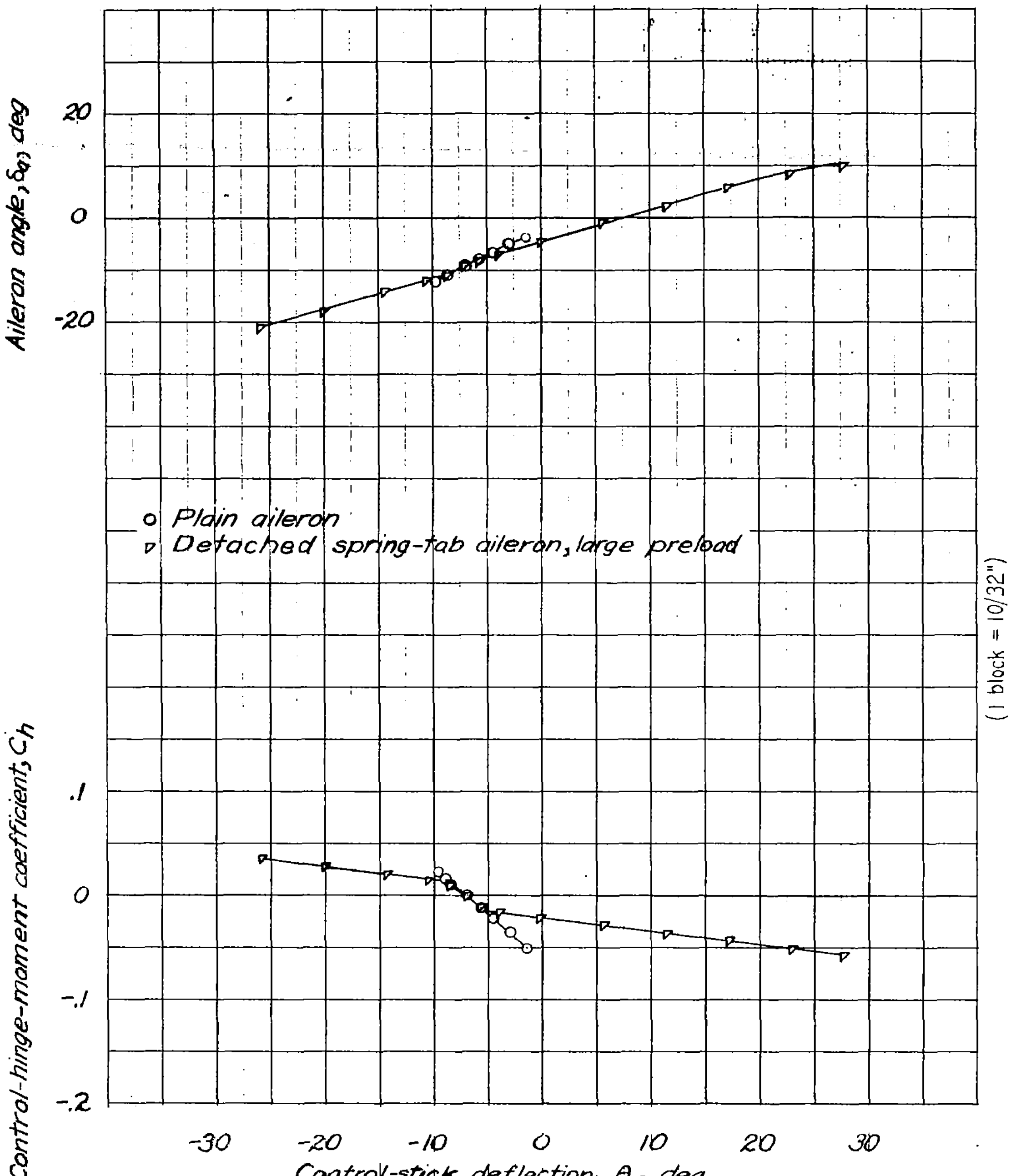


Figure 12. - Variation of aileron angle and control-hinge-moment coefficient with control-stick deflection for plain and detached spring-tab ailerons. $\alpha = 9.5^\circ$; $q = 65$ pounds per square foot.

L-713

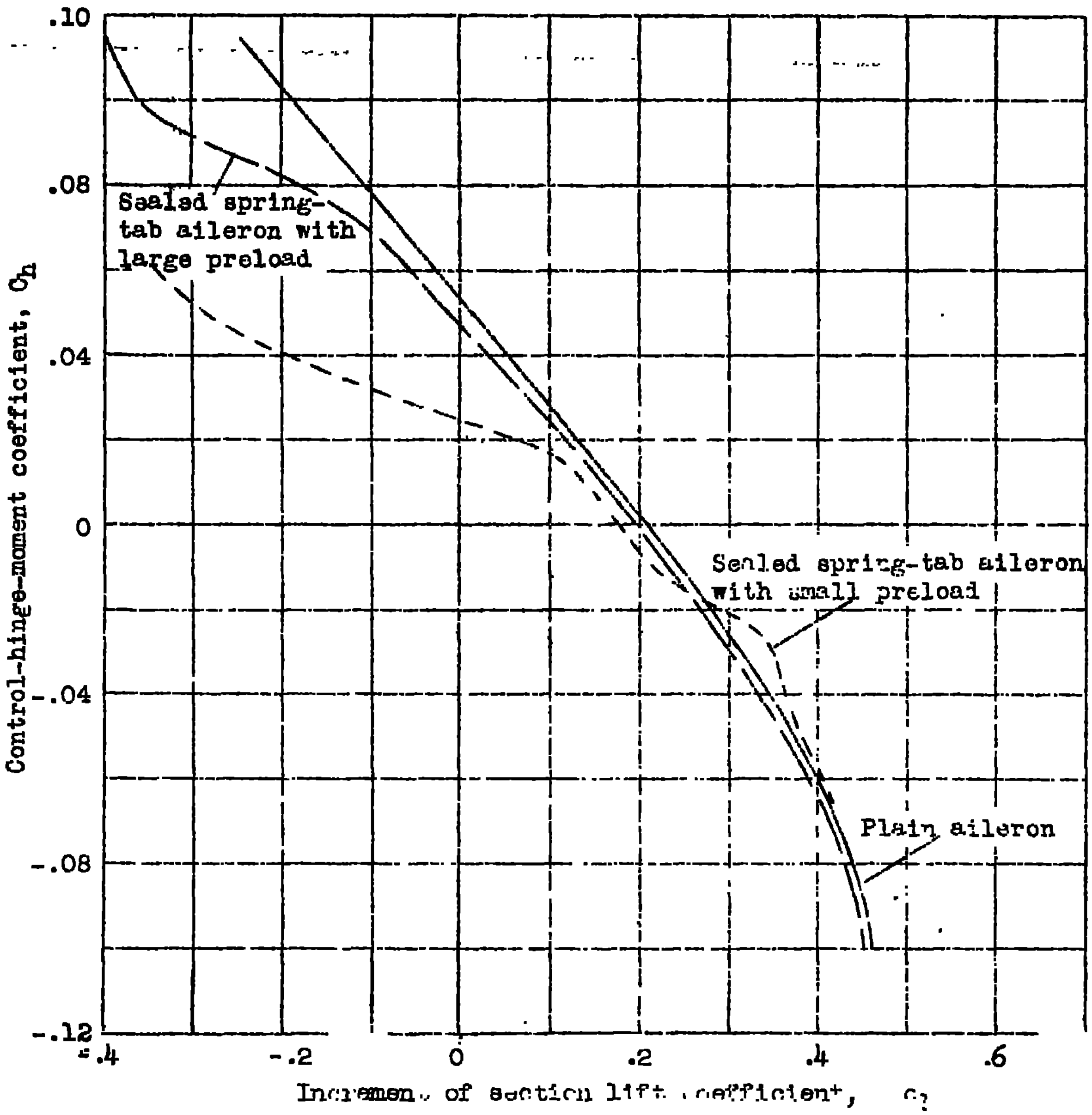


Figure 13.- Variation of control-hinge-moment coefficient with increment of section lift coefficient for plain and spring-tab ailerons. $\sigma = 0^\circ$; q = 25 pounds per square foot.

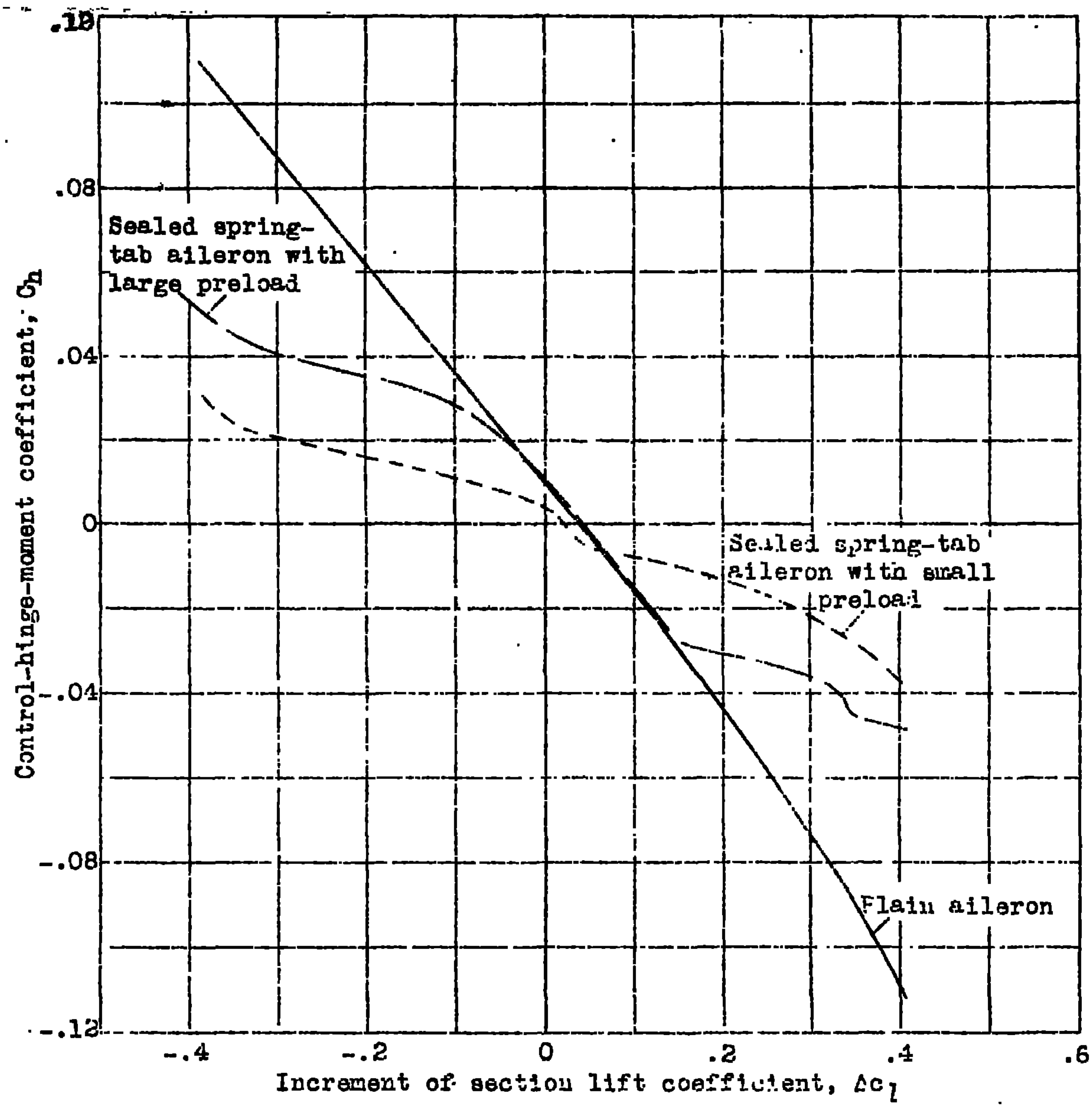


Figure 14.- Variation of control-hinge-moment coefficient with increment of section lift coefficient for plain and spring-tab ailerons. $\alpha = 0^\circ$; $q = 65$ pounds per square foot.

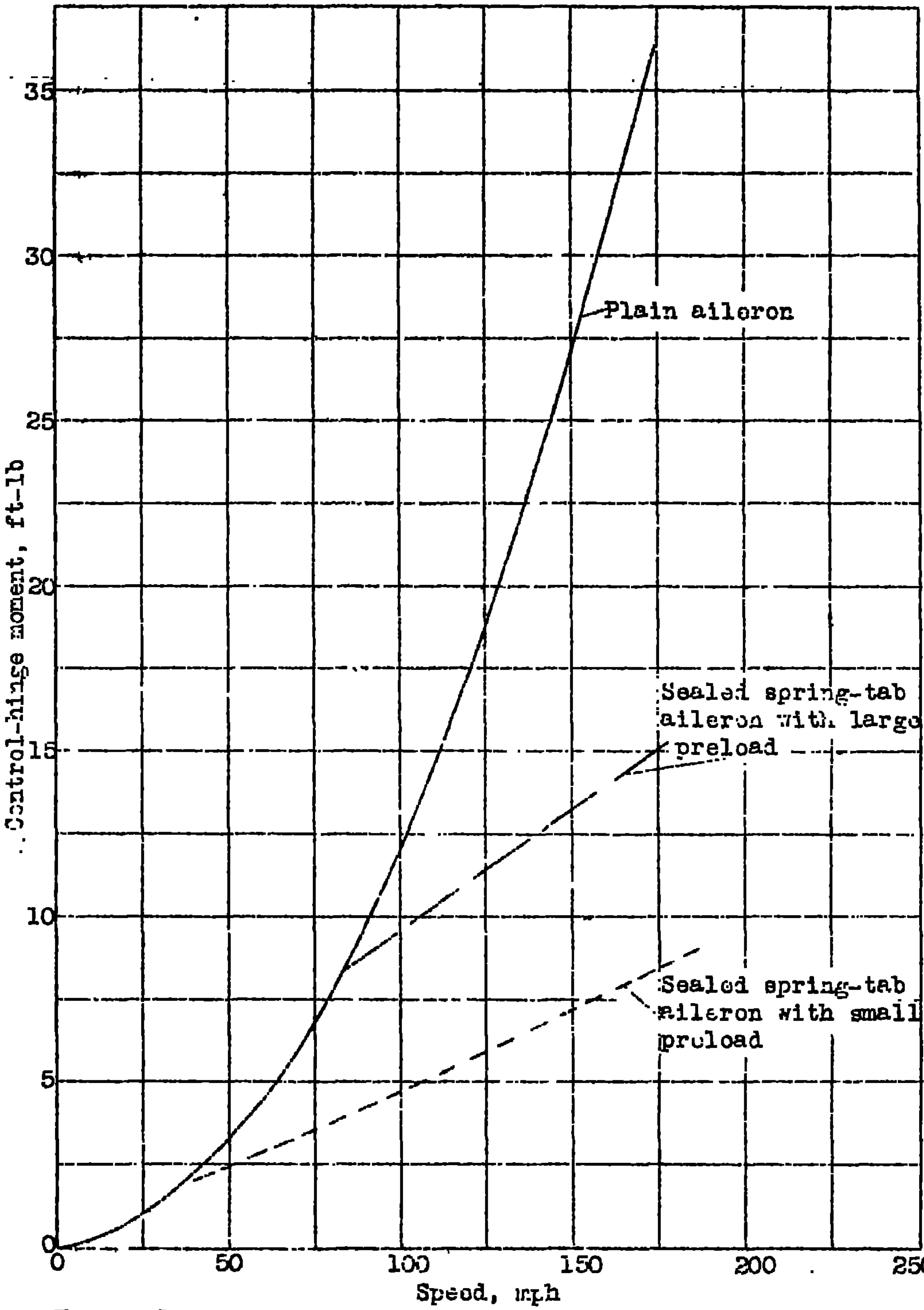


Figure 15.- Variation of control-hinge moment with speed for the plain aileron and the sealed spring-tab aileron. Control deflected to give a change in Δc_l of -0.4 from zero hinge moment. $\alpha = 0^\circ$.

L-310

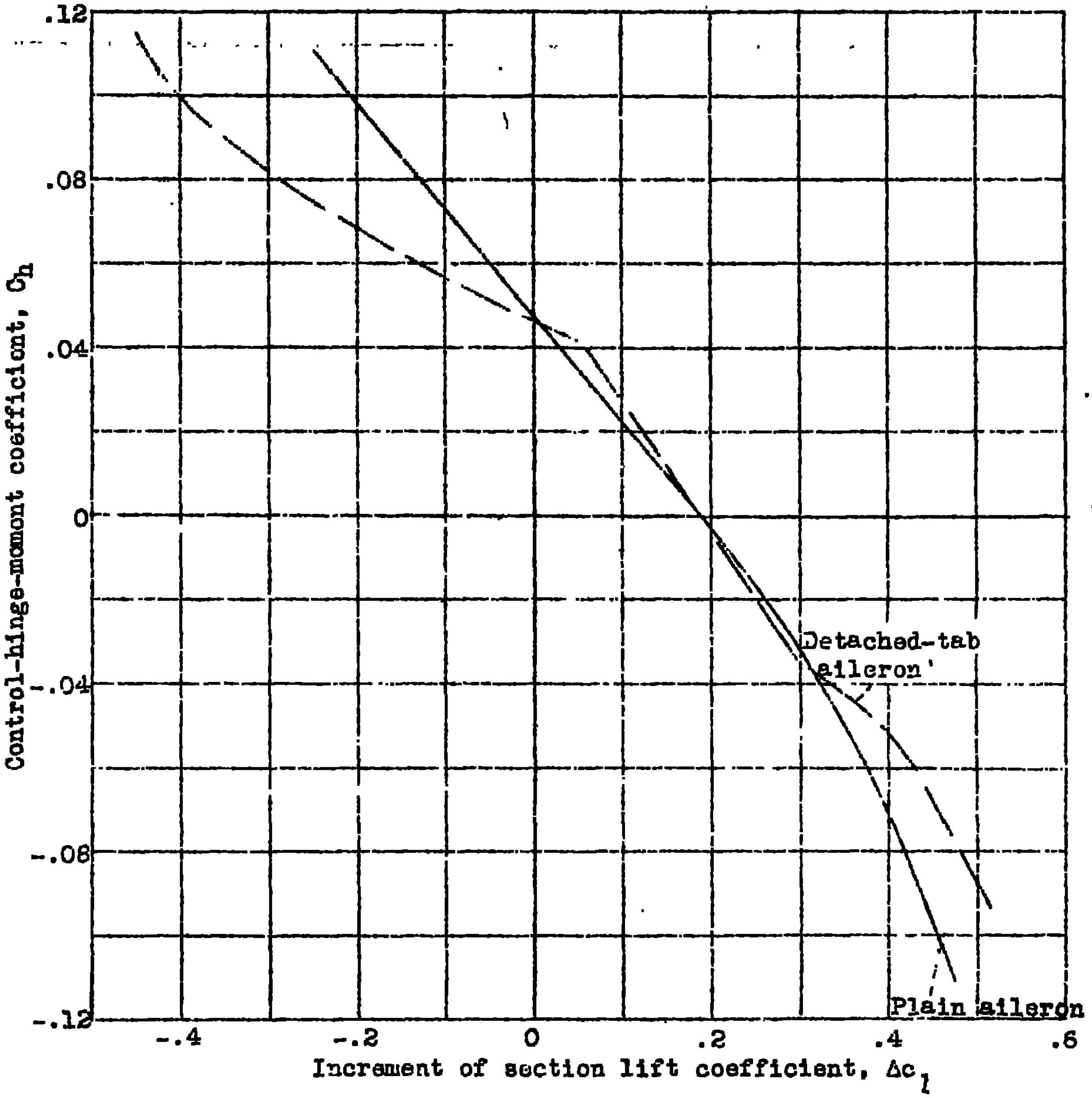


Figure 16.- Variation of control-hinge-moment coefficient with increment of section lift coefficient for plain and detached-tab ailerons. $\alpha = 0^\circ$; q = 25 pounds per square foot.

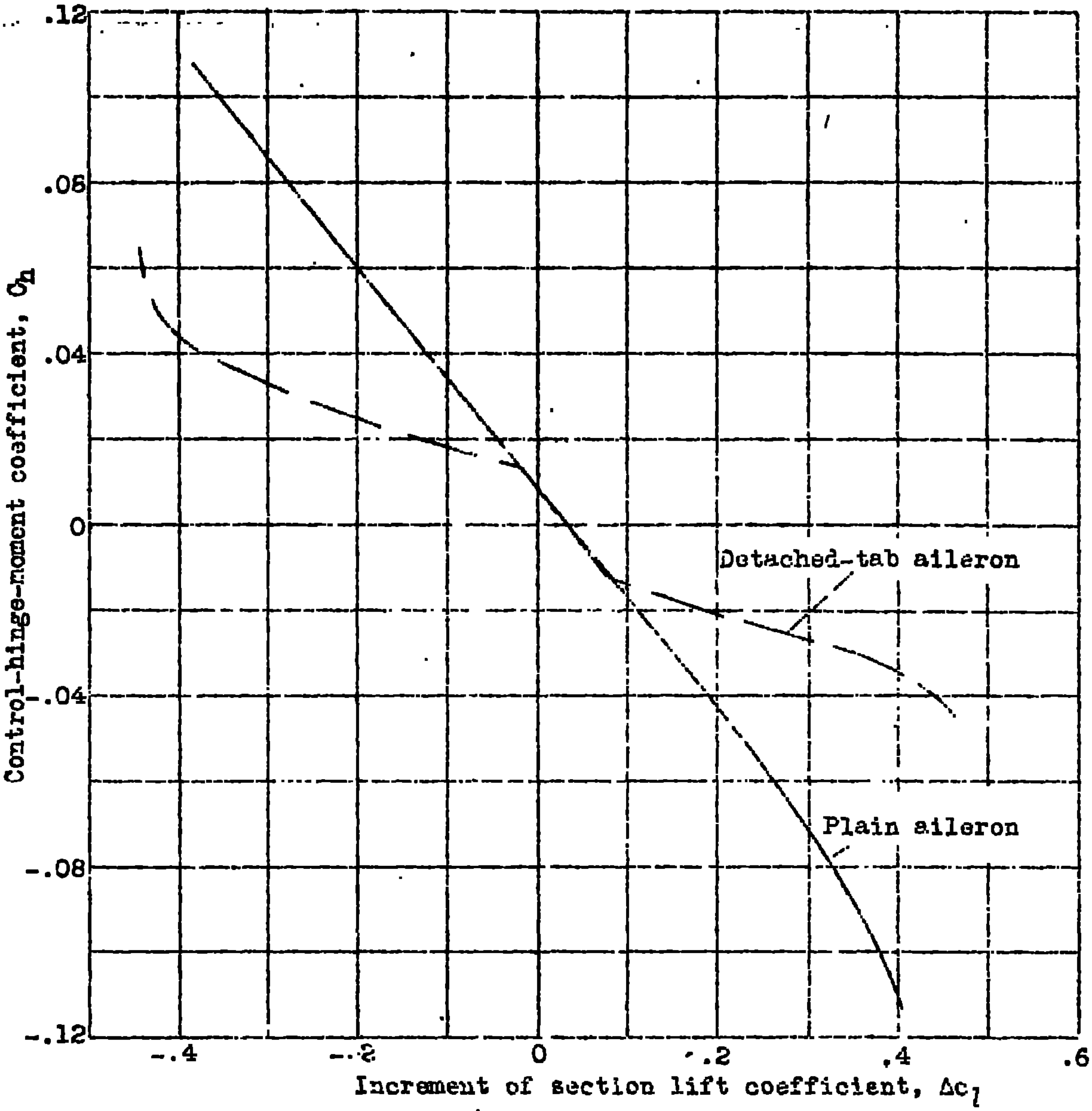
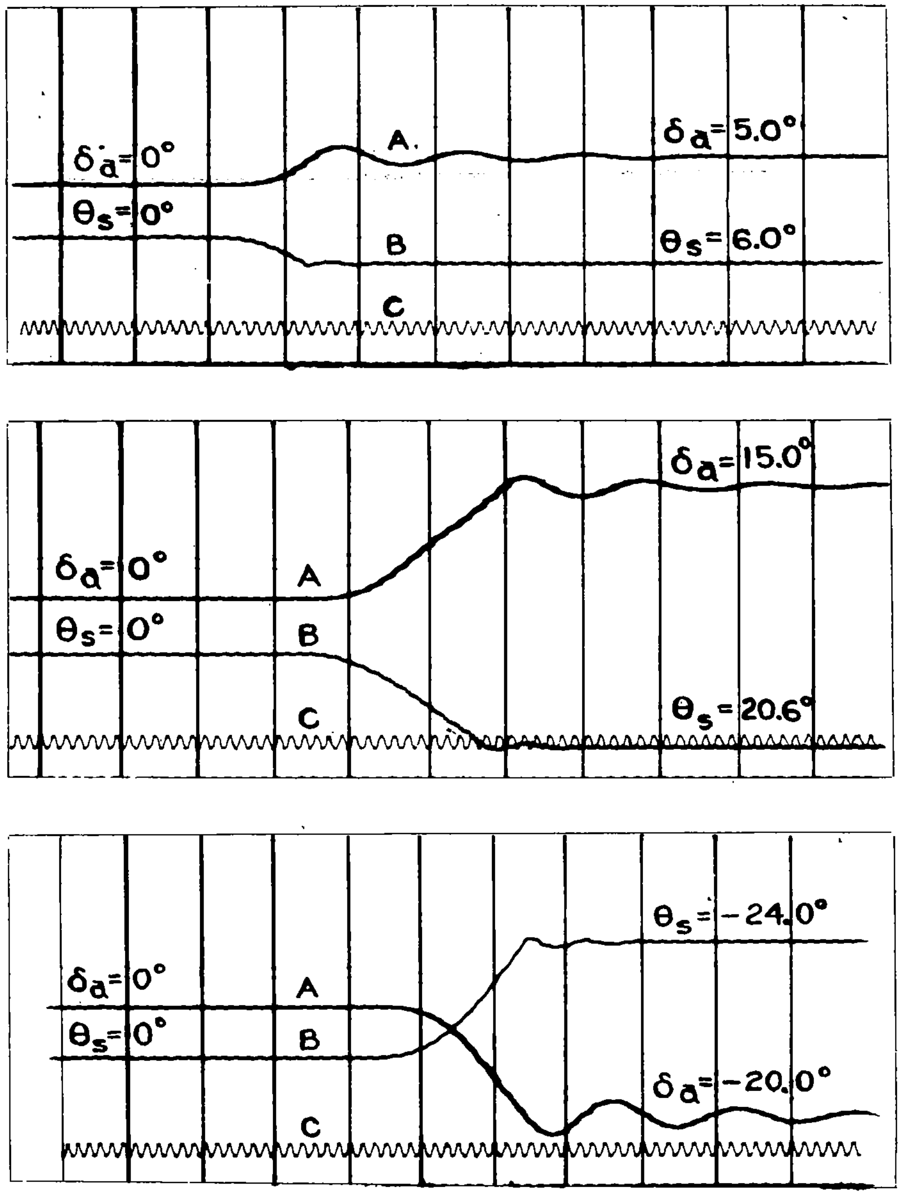


Figure 17.- Variation of control-hinge-moment coefficient with increment of section lift coefficient for plain and detached-tab ailerons. $\alpha = 0^{\circ}$; q = 65 pounds per square foot.



Curve
A aileron deflection
B control-stick deflection
C 60 cycles per second timing line

Vertical lines are 1/10 second timing lines

Figure 18. - Typical records of aileron and control-stick deflections for aileron with sealed trailing-edge spring tab with small preload. $\alpha = 9.5^{\circ}$; $q = 25$ pounds per square foot.

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